DEVELOPMENT OF A HIGH FIDELTY DYNAMIC MODULE OF THE ADVANCED RESISTIVE EXERCISE DEVICE (ARED) USING ADAMS®

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NASA's Digital Astronaut Project (DAP) implements well-vetted computational models to predict and assess spaceflight health and performance risks, and enhance countermeasure development. DAP provides expertise and computation tools to its research customers for model development, integration, or analysis.

DAP is currently supporting the NASA Exercise Physiology and Countermeasures (ExPC) project by integrating their biomechanical models of specific exercise movements with dynamic models of the devices on which the exercises were performed. This presentation focuses on the development of a high fidelity dynamic module of the Advanced Resistive Exercise Device (ARED) on board the ISS. The ARED module, illustrated in the figure below, was developed using the Adams (MSC Santa Ana, California) simulation package.

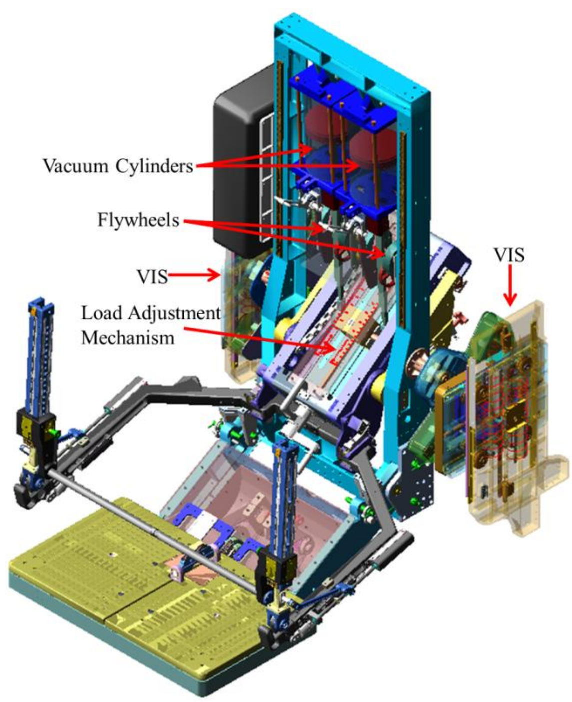
The Adams package provides the capabilities to perform multi rigid body, flexible body, and mixed dynamic analyses of complex mechanisms. These capabilities were applied to accurately simulate:

- Inertial and mass properties of the device such as the vibration isolation system (VIS) effects and other ARED components
- Non-linear joint friction effects
- The gas law dynamics of the vacuum cylinders and VIS components using custom written differential state equations
- The ARED flywheel dynamics, including torque limiting clutch

Design data from the JSC ARED Engineering team was utilized in developing the model. This included solid modeling geometry files, component/system specifications, engineering reports and available data sets.

The Adams ARED module is importable into LifeMOD (Life Modeler, Inc., San Clemente, CA) for biomechanical analyses of different resistive exercises such as squat and dead-lift. Using motion capture data from ground test subjects, the ExPC developed biomechanical exercise models in LifeMOD. The Adams ARED device module was then integrated with the exercise subject model into one integrated dynamic model.

This presentation will describe the development of the Adams ARED module including its capabilities, limitations, and assumptions. Preliminary results, validation activities, and a practical application of the module to inform the relative effect of the flywheels on exercise will be discussed.



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National Aeronautics and Space Administration

BACKGROUND

NASA's Digital Astronaut Project (DAP) Vision

The Digital Astronaut Project implements well-vetted computational models to predict and assess spaceflight health and performance risks, and enhance countermeasure development, by

- Partnering with subject matter experts to inform HRP knowledge gaps and countermeasure development decisions;
- Modeling and simulating the adverse physiologic responses to exposure to reduced gravity and analog environments; and
- Ultimately providing timely input to mission architecture and operations decisions in areas where clinical data are lacking.

HRP Risks/Gaps Addressed by This Effort

Risk of Muscle Atrophy: impaired performance due to reduced muscle mass, strength and endurance

- **Gap M7:** Can the current in-flight performance be maintained with reduced exercise volume?
- **Gap M8:** What is the minimum exercise regimen needed to maintain fitness levels for tasks?
- **Gap M9:** What is the minimum set of exercise hardware needed to maintain those fitness levels?

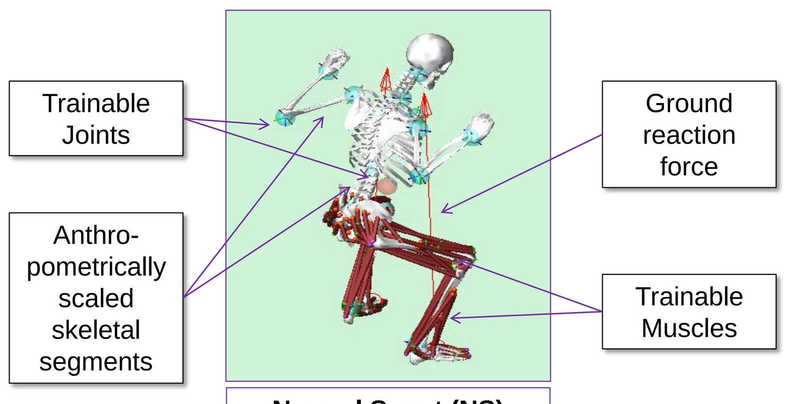
Risk of Loss of Bone Mineral Density: early onset of osteoporosis and bone fracture

- **Gap B15:** (a) What exercise protocols are necessary to maintain skeletal health and (b) can exercise hardware be designed to provide these?
- **Gap B1:** (a) Is there an increased lifetime risk of fragility fractures/osteoporosis in astronauts; (b) is bone strength completely recovered post-flight, and does BMD reflect it; (c) what are the risk factors for poor recovery of BMD/bone strength?

INTEGRATED BIOMECHANICAL AND DEVICE MODELING

Biomechanical Module[1] (Wyle Intg. Sci. & Engr.)

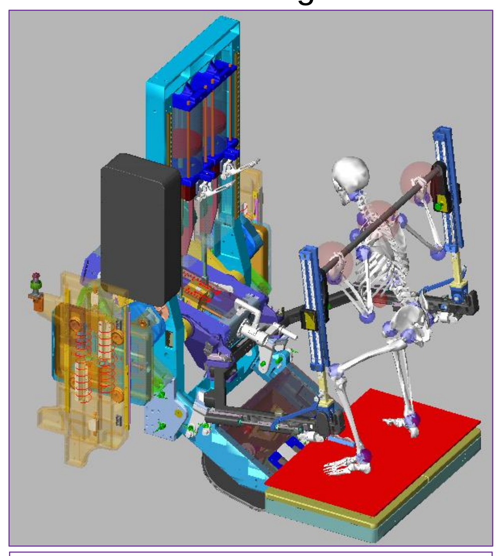
•Forward dynamics modules in LifeMOD® (a plug-in to ADAMS®) representative of the subject's anthropometrics and motions during the performance of various exercises, including squat, single-leg squat and deadlift



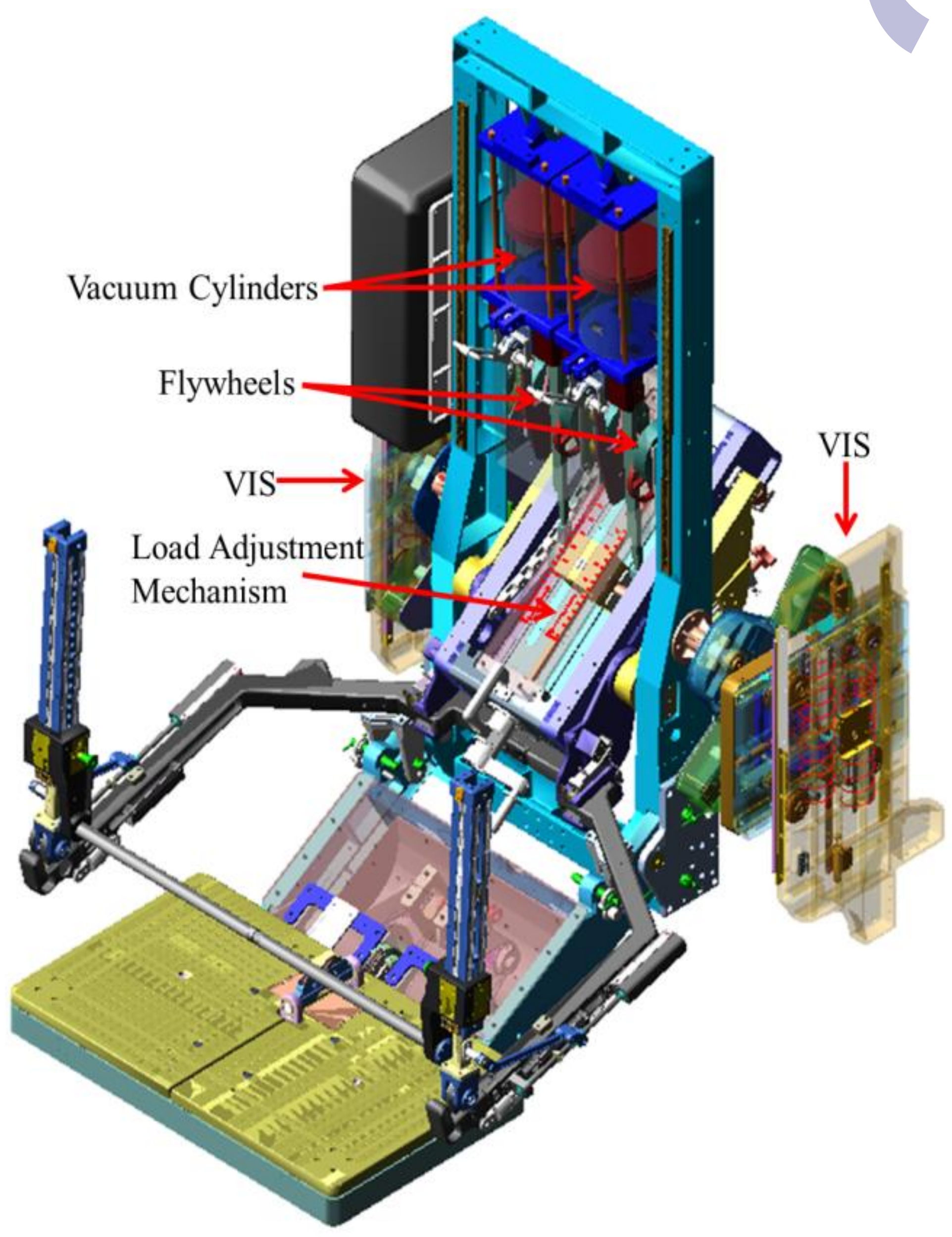
Normal Squat (NS) Module (LifeMOD®)

Integrated Device & Biomechanics Module (NASA GRC)

• ARED Module and Biomechanical module integrated and simulated together



Integrated Module (LifeMOD®)



ARED Device Module[2,3] (ZIN Technologies)

•Capabilities
- Directly importable into LifeMOD®
- Full configurable device (load setting, bar position, etc.)
- Forward and Inverse (kinematic) driven dynamics
- Configurable for ground or ISS (VIS) use
- Inertial and mass properties of the device such as vibration isolation system (VIS) effects and other ARED components
- Non-linear joint friction effects
- Gas law dynamics of vacuum cylinders and VIS components using custom written differential state equations
- ARED Flywheel dynamics, including torque limiting clutch

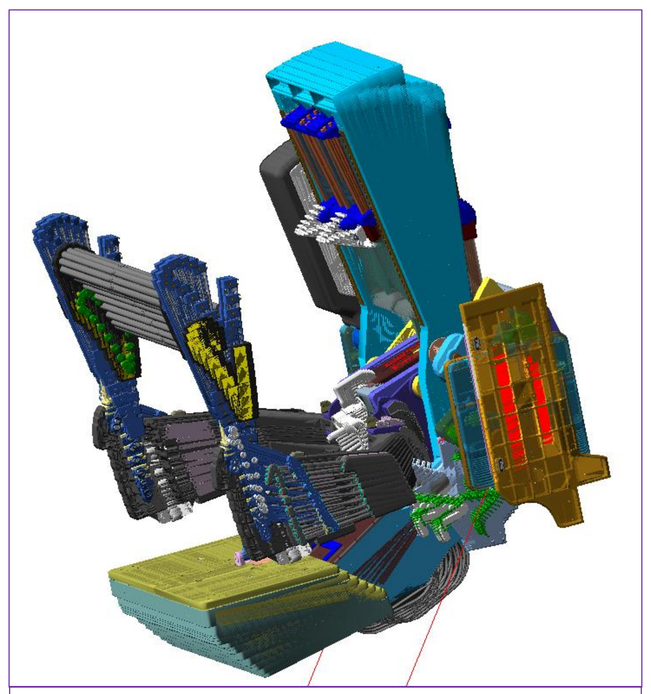
•Limitations
- Bar Exercise Only (Cable Exercises not implemented)
- Rigid body dynamics

•Source Data (JSC ARED Engineering Team)
- Solid modeling geometry data
- Component /System Specifications
- Engineering verification data sets

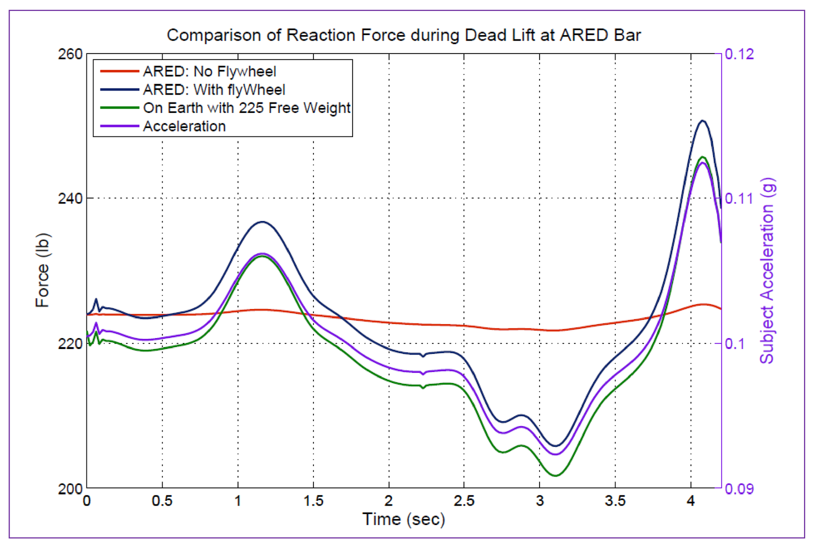
EXAMPLE DEVICE ANALYSES

Flywheel Analysis

- Goal: Analyze Flywheel Contribution on ARED
- Flywheels
  - Augment vacuum cylinders which simulate constant force component
  - Simulate the acceleration response similar to that seen in lifting a free weight
  - Flywheels by design provide approximately 20% of the reaction force during exercise (load setting and motion dependant)
  - Utilize a torque limiting clutch to limit acceleration response
  - Can be engaged or disengaged by the subject
- Impetus – Flight unit flywheel's were experiencing slippage. Desired to quantify the effect on using the ARED with flywheels disengaged,
- Analysis Description
  - ExPC Team at JSC collected motion capture data of subjects performing squat and deadlift on ARED ground unit
  - Motion capture data was then used to drive inverse dynamics of ARED Adams module
  - Analysis performed with and without the flywheels engaged
  - Results also compared to lifting a free-weight mass in 1-g with same motion



Superimposed Motion Plot of ARED (Adams)
Note VIS Reaction



Support of Additional Integrated Analyses

- See Posters:
  - "*Integrated Biomedical Modeling of the Squat Exercise on the Advanced Resistive Exercise Device (ARED) Using LifeMOD*" (Poster #4111)
  - "*The Musculoskeletal Modeling Component of the NASA Digital Astronaut Project*" (Poster #4184)

VERIFICATION AND VALIDATION

- Compare quasi-static load versus displacement
- Compare mass properties to design and measured data
- Compare model rigid body modes to design calculation and requirements
- Compare VIS and device kinematics to ISS video data
- Compare to JSC ARED engineering teams design verification data
- Conform to NASA-STD-7009 standards for assessing the credibility of computational models

DISCUSSION/SIGNIFICANCE

Accomplishments to date

- Detailed ARED Adams ® model completed
- Model utilized with comparison of ground motion capture data to understand contribution of flywheel on mass simulation
- Completing Validation of Adams Module
- Successful integration with LifeMod ®

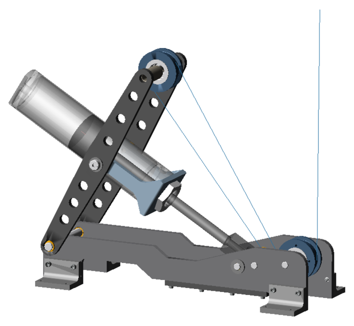
Significance

- High fidelity simulation of device reaction to subject motion
- Inclusion of Vibration isolation system in response dynamics allows for use of on-orbit data

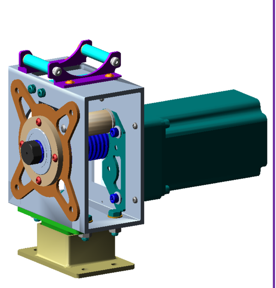
FUTURE WORK

Additional Devices

- Models of other exercise devices
  - ZIN Cam Air Spring Device (Fig. a)
  - Multi-mode Exercise Device – NSBRI
  - Streamline® Compact Controlled Force Exercise Device – SBIR (Fig. b)



(Fig. a)



(Fig. b)

Development of Generic Device Model

- Represent passive devices as 2nd order lumped parameter model (spring, mass, damper, columbic friction, and constant force)
- Calculate parameters for detailed model device
- Build generic parameter device model
- Model will allow for Validation with OpenSim®

ACKNOWLEDGEMENTS

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PARTNERS

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